Emission trading and labor market rigidity inan international duopoly model

Tarik Tazdaït, Alejandro Caparros, Jean-Chrsitophe Péreau

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A. Caparros[*], J.-C. Pereau[†] and T. Tazdaït[‡]

Abstract

Emission trading systems have been recently proposed in different regions to reduce polluting emissions (e.g. in the European Union for carbon dioxide). One of the objectives of these systems is to encourage firms to adopt advanced abatement technologies. However permits create an incentive to reduce production, which may be seen as negative by policy makers. Combining the emission trading system with a more rigid labour market, we show conditions under which it is possible to avoid this impact keeping the incentives to improve abatement technologies. The analysis is done for oligopolistic firms engaged in international rivalry.

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[*]Department of Economics, Institute of Economics and Geography (IEG), Spanish Council for Scientific Research (CSIC), Pinar 25, 28006 Madrid, Spain. Tel.: +34.91.411.10.98. Fax: +34.91.562.55.67. Email: acaparros@ieg.csic.es.

[†]OEP, University of Marne-la-Vallée Cité Descartes, 5 bd Descartes, Champs sur Marne, Marne la Vallée Cedex 2, France. Email : pereau@univ-mlv.fr

[‡]CIRED (CNRS-EHESS) Jardin Tropical, 45 bis av de la belle Gabrielle, 94736 Nogent sur Marne Cedex, France. Email : tazdait@centre-cired.fr.

1 Introduction

The European Union has decided to launch an emission trading system for five energy intensive sectors[1]. One of the objectives of this carbon dioxide emission trading system is to create an incentive to adopt advanced abatement technologies: "This Directive will encourage the use of more energy-efficient technologies ..."[2], see also European Commission (2005). Extensive literature[3] has investigated the convenience of a permits system to reach this objective (Montero, 2002; Requate and Unold, 2003). However, launching an emission trading system may have an additional impact: create incentives to reduce production (Gielen and Moriguchi, 2002). We analyze this impact, which will generally be seen as negative, studying the conditions under which this impact can be eliminated keeping the benefit of encouraging advanced abatement technologies.

Since we are interested in analyzing this issue in an international setting, we build on the model developed by Spencer and Brander (1983) to study R&D incentives and international rivalry. Thus, we assume duopolistic competition in a national market between a domestic and a foreign firm. The assumption of imperfect markets is well suited for the sectors affected by the EU directive (Antweiler and Trefler, 2002). We further assume that the domestic country or region (e.g. the European Union) establishes an emission trading system, while the foreign country (e.g. the United States) does not[4]. This implies that the firm producing in the domestic country has to pay the permit price β when its emissions exceed a limit E of permits grandfathered. Conversely, when the emissions of the firm producing in the domestic country are lower than this limit E, the firm can sell permits at the price β. Since the proposal of emission trading in Europe is focused on energy intensive sectors, we assume that the main inputs in the firm's production function are energy, technology (capital) and labor.

We also analyze the impact of a second big difference between the conditions under which an American (foreign country) and at least some European (domestic country) firms produce: the rigidity of their labor markets. We do not study possible revenue-recycling effects or the impact of distortionary

[1] The sectors are: (i) electricity and heat generation, (ii) iron and steal, (iii) glass, pottery and building materials, (iv) refineries and (v) paper and pulp. (Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003).

[2] Directive 2003/87/EC, whereas (20).

[3] See Jaffe *et al.* (2003) for a survey.

[4] The European Union has ratified the Kyoto Protocol on climate change and started the process to launch an emission trading system (see above). The United States has announced its opposition to the Kyoto Protocol and proposed to fight climate change through a voluntary approach. However, our analysis is not limited to the Kyoto Protocol.

taxes, as has been done in most of the literature that has linked environmental policy (mainly taxes) and labor markets (Bovenberg and Goulder, 1996; Parry *et al.*, 1999). On the contrary, we link environmental policy and labor policy to avoid the negative impacts on production decisions of the former.

The analysis entails a sequential decision. In a first stage firms choose technology, while production and sales occur in a second stage. We suppose that the government is not interested in emission reductions obtained through reductions in production (due to undesired impacts on employment and growth), while it is interested in emission reductions induced by technological changes. Since it is easy to show that setting up an emission trading system implies production reductions, we analyze the possibility to avoid these consequences via an increase in labor market rigidity. We obtain the conditions under which this is possible, keeping the benefits of the emission trading system (enhanced abatement technologies). Given the international rivalry context analyzed, we focus on relative levels of technology.

The article is organized as follows. Section 2 describes the basic model. Section 3 studies optimal production decisions. Section 4 analyzes optimal technology decisions. Section 5 concludes.

2 The model

There are two countries, designated by the subscripts $n = 1, 2$ (we will also call them, respectively, domestic and foreign country). The exchange rate between these two countries is constant.

A single homogeneous good is sold in a duopolistic market in country 1. Each country has a representative firm whose sales are denoted y_n. The duopoly equilibrium arises from the sales: $y_1 + y_2$. Cournot-Nash behavior is assumed. We focus, for simplicity, on the firms relative competitiveness for selling in the duopolistic market of country 1 (i.e. we do not consider sales in country 2). The revenue function is denoted $R_n(y_1, y_2)$. The following standard assumptions apply[5], for $\forall n \in (1, 2)$ and $\forall i, j \in (1, 2)$:

$$R_n^i > 0; R_n^j < 0; R_n^{ii} < 0; R_n^{jj} > 0 \text{ and } R_n^{ij} < 0; \tag{1}$$

Outputs y_1 and y_2 are substitutes. Increasing the output of one good decreases the marginal revenue of the other good. Energy inputs (e_n), technology (x_n) and labor (l_n) are the main components in the firms' production

[5]Superscripts are used to denote the letter entry in a function for which differentiation is done. The number indicates the order of the letter in the definition of the function. That is: $R^1(y_1, y_2) = \frac{\partial R(y_1, y_2)}{\partial y_1}$, and $R^{12}(y_1, y_2) = \frac{\partial^2 R(y_1, y_2)}{\partial y_1 \partial y_2}$.

function: $y_n = f_n(e_n, x_n, l_n)$. An essential assumption is that the production of each firm takes place in its home country.

The unit costs of energy is given by p_1 and p_2. To simplify we assume that these prices are per unit of emissions associated to a given energy[6] (i.e. we give the price not in tons of oil but in tons of CO_2 associated to a ton of oil).

Country 1 is assumed to have an emission trading market (since we are under perfect information, similar results would be obtained using a tax). Hence, firms in country 1 have to pay β (permit price) whenever the number of tons of carbon emitted (e_1) is higher than a given amount of permits grandfathered E. The value of the latter variable determines if firms are "environmentally constrained" (i.e. $E < e_1$). Hence, for $E < e_1$ the firm has an additional cost owing to the need to buy permits, while for $E > e_1$ the firm has an additional source of benefits (the income of the permits sold). The domestic firm, although a duopolist in its main market, is supposed to be too small to influence the price in the emission trading market, a market that covers several sectors. Therefore, firm 1 is price-taker in the emission trading market and cannot influence β. In country 2, no emission trading is established, nor any other abatement measure such as carbon taxes.

Labor (l_n) has a wage cost of w_n. We assume that country 1 has a rigid market, where redundancy cost μ arises when a firm wants to reduce its labor force below a historical level L (no redundancy costs exist in country 2). The value of this latter variable determines if firms are "socially constrained", in the sense that $L > l_1$. We will assume that this relation always holds.

Technology (x_n) covers all kind of investments which increase productivity of energy (CO_2 emissions) via technology. It can be seen as capital or as R&D investments (Spencer and Brander, 1983). The net cost of investing in technology (x_n) is determined by the unit cost of technology (v_n).

Energy, technology and labor inputs are characterized by either decreasing or constant returns. Energy efficiency is either increasing or constant as technology investment increases, and so is labor efficiency. By the same token, technology efficiency is either increasing or constant as labor investment increases. Thus, the following relations hold, for $\forall n \in (1, 2)$ and $\forall i, j \in (1, 2, 3)$:

$$f_n^i > 0;\ f_n^{ii} \leq 0 \text{ and } f_n^{ij} \geq 0 \tag{2}$$

In certain of the subsequent derivations it will be essential to make explicit reference to the demand for energy, which entails an inversion of the production function: $e_n = k(y_n, x_n, l_n)$. Accordingly, we have the following set

[6] We could also use αe_1 for emissions and e_1 for energy but it would complicate the results with no real gain.

of assumptions regarding the partial derivatives for this inverse function, for $\forall n \in (1,2)$ and $\forall i, j \in (1,2,3)$:

$$k_n^i > 0; k_n^j < 0; k_n^{ii} \geq 0 \text{ and } k_n^{ij} \leq 0$$

In the same way, we shall use the demand for labor $l_n = h(y_n, x_n, e_n)$. For $\forall n \in (1,2)$ and $\forall i, j \in (1,2,3)$ we have:

$$h_n^i > 0; h_n^j < 0; h_n^{ii} \geq 0 \text{ and } h_n^{ij} \leq 0$$

In addition, all third order derivatives for k and h are assumed to be zero, i.e. $k^{ijm} = h^{ijm} = 0, \forall\ i, j, m \in (1,2,3)$.

Taking into account these assumptions, we have the following asymmetric specifications for the domestic and the foreign firms' profit functions:

$$\Pi_1 = R_1(y_1, y_2) - p_1 e_1 - w_1 l_1 - v_1 x_1 - \beta(e_1 - E) - \mu(L - l_1) \tag{3}$$
$$\Pi_2 = R_2(y_1, y_2) - p_2 e_2 - v_2 x_2 - w_2 l_2 \tag{4}$$

with $L > l_1$, $e_n = k(y_n, x_n, l_n)$ and $l_n = h(y_n, x_n, e_n)$.

Firms optimize sequentially the values for y_n and x_n, starting with its technology decisions. In the first stage, abatement technology decisions are made anticipating their impact on production decisions in the following stage (production decisions give energy and labor requirements, once the technology is fixed). Since we have a two stages game with complete information, the equilibrium concept to be used is the Subgame Perfect Equilibrium (SPE) proposed by Selten (1965, 1975). The SPE assumes common expectations on player's behavior. That is, each player holds a correct conjecture about the opponent's strategic choices. The strategies of firms 1 and 2 form an SPE if the strategies form a Nash equilibrium on each stage of the game. However, since we work with general functions, studying the existence and the uniqueness of the SPE explicitly is rather complicated. Thus, we will characterize the behavior of the firms by means of a comparative statics analysis.

3 Firms' optimal production decisions

The solutions for the model are determined iteratively, in a standard fashion, by backward induction, analyzing first the second stage (optimal output levels of the firms), given the technology decisions taken on stage 1. Thus, in this section we offer an initial characterization of the asymmetric nature of the *ex post* output decisions of both firms, focusing on the situation where a duopoly prevails in the domestic market. Specifically, a duopoly outcome arises when:

$$R_1(y_1, y_2) \geq p_1 e_1 + w_i l_i + \beta(e_1 - E_1) + \mu(L - l_1), \text{ with } L > l_1 \tag{5}$$

However, when this condition does not hold, the domestic firm faces an environmental and/or social constraint that forces it to shut down and the foreign firm takes over the entire domestic market. Our modelling assumptions entail concave revenue functions and production functions which are either concave or linear in energy use for, respectively, the cases of decreasing and constant returns to scale. Since the domestic firm's marginal revenue is falling as output increases, whereas its marginal costs are either constant or rising, the inequality in (5) will be reversed for sufficiently large values of y_1.

Nevertheless, as stated, we will focus on the duopoly outcome when condition (5) is fulfilled. Under the Cournot-Nash assumption, the first-order conditions (which give firms' reaction functions) are:

$$\begin{aligned}
\Pi_1^1(y_1, y_2, x_1, l_1, e_1) &= R_1^1 - (p_1 + \beta)k_1^1 - (w_1 - \mu)\, h_1^1 = 0 & (6)\\
\Pi_2^2(y_1, y_2, x_1, l_1, e_1) &= R_2^2 - p_2 k_2^1 - w_2 h_2^1 = 0 & (7)\\
\Pi_1^2 &= R_1^2 < 0, \ \Pi_2^1 = R_2^1 < 0 & (8)
\end{aligned}$$

The second-order conditions for a profit maximum are:

$$\begin{aligned}
\Pi_1^{11} &= R_1^{11} - (p_1 + \beta)k_1^{11} - (w_1 - \mu)\, h_1^{11} < 0\\
\Pi_2^{22} &= R_2^{22} - p_2 k_2^{11} - w_2 h_2^{11} < 0\\
\Pi_1^{12} &= R_1^{12} < 0, \ \Pi_2^{21} = R_2^{21} < 0
\end{aligned}$$

Given these second-order conditions, it is clear that an assumption that the wage rate is greater than potential redundancy costs for a representative worker ($w_1 - \mu > 0$) is a sufficient condition to guarantee that the domestic firm's reaction function is downward sloping. For simplicity, we will assume that this inequality always holds. We further assume that the other standard conditions for existence of duopoly equilibrium apply (in order to ensure uniqueness and global stability of the equilibrium): $A = \Pi_1^{11}\Pi_2^{22} - \Pi_1^{12}\Pi_2^{21} > 0$, $\Pi_1^{11} < 0$ and $\Pi_2^{22} < 0$. The implicit Cournot-Nash equilibrium solutions of these conditions can be denoted as $y_1^* = q_1(x_1, x_2)$ and $y_2^* = q_2(x_1, x_2)$.

Total differentiation of the first-order conditions gives:

$$\begin{aligned}
d\Pi_1^1 &= 0 = \Pi_1^{11} dy_1 + \Pi_1^{12} dy_2 - [(p_1 + \beta)k_1^{12} + (w_1 - \mu)\, h_1^{12}]dx_1\\
&\quad -(p_1 + \beta)k_1^{13} dl_1 - (w_1 - \mu)\, h_1^{13} de_1\\
d\Pi_2^2 &= 0 = \Pi_2^{22} dy_2 + \Pi_2^{21} dy_1 - \left[p_2 k_2^{12} + w_2 h_2^{12}\right] dx_2 - p_2 k_2^{13} dl_2 - w_2 h_2^{13} de_2
\end{aligned}$$

Substituting, we have:

$$\begin{aligned}
q_1^1 &= dy_1/dx_1 = [(p_1+\beta)k_1^{12} + (w_1-\mu)\,h_1^{12}]\Pi_2^{22}/A > 0 \\
q_1^2 &= dy_1/dx_2 = -\left[p_2 k_2^{12} + w_2 h_2^{12}\right]\Pi_1^{12}/A < 0 \\
q_1^2 &= dy_2/dx_1 = -[(p_1+\beta)k_1^{12} + (w_1-\mu)\,h_1^{12}]\Pi_2^{21}/A < 0 \\
q_2^2 &= dy_2/dx_2 = \left[p_2 k_2^{12} + w_2 h_2^{12}\right]\Pi_1^{11}/A > 0
\end{aligned}$$

Taking the total differential of the first-order condition for the domestic firm, we have:

$$\frac{dy_2}{dy_1} = \frac{-\Pi_1^{11}}{\Pi_1^{12}} = \frac{-\left[R_1^{11} - (p_1+\beta)k_1^{11} - (w_1-\mu)h_1^{11}\right]}{R_1^{12}} < 0 \tag{9}$$

Note that an increase in the value of β leads to smaller values for the numerator in (9), generating (*ceteris paribus*) a steeper slope for the downward sloping reaction function of firm 1 (in the scenario where that firm is environmentally constrained and a duopoly solution still applies). As expected, this leads to a lower (higher) level of equilibrium output for the domestic (foreign) firm.

This result enables us to write the following proposition:

Proposition 1 *Setting up an emission trading system induces the domestic firm to reduce its level of production.*

Figure 1 illustrates the competitive effects on the output (sales) shares of both firms, which result from a hypothetical structural change where firm 1 faces a more stringent emission trading market due to an increase in the permit price. As a result of higher permit prices ($d\beta > 0$) the reaction function[7] of firm 1 (RF_1) gets steeper and the Cournot-Nash equilibrium shifts from N to N' (reducing the market share of firm 1).

On the contrary, an increase in the value of μ leads to a larger value for the numerator in (9), generating (*ceteris paribus*) a flatter slope for the downward sloping reaction function of firm 1 (in the scenario where that firm is socially constrained and a duopoly solution still applies). In turn, this will lead to a higher (lower) level of equilibrium output for the domestic (foreign) firm. Just the opposite of the result we obtained for the emission trading. This result enables us to write the following proposition:

[7] Note that the reaction function of firm 1 (RF_1) is truncated for high levels of y_1, owing to the social and environmental constraints which can force the firm out of the market for high levels of production. Thus, it is easy to draw a situation where RF_1 and RF_2 do not cross at any point.

Proposition 2 *Setting up a social constraint induces the domestic firm to increase its level of production.*

This result shows that a rigid market can be a protection against the output reduction induced by the emission trading scheme. Of course, this is only possible as long as the survival of the firms is not endangered (however, in sectors with strong market power this survival will generally not be threatened).

The intuition for this result is that when a firm is socially constrained it faces non-redeemable sunk costs associated with dismissing workers. As long as inequality (5) holds, the firm faces a trade-off between, on the one hand, accepting additional variable production costs associated with higher output levels (including the marginal wage bill of maintaining workers) and, on the other hand, paying the costs of dismissing existing employees. Due to this trade-off, the socially constrained firm will be induced to obtain a larger market share than a competitor operating in a flexible labor market. Hence, higher redundancy costs can be seen as decreasing net variable wage costs, as reflected by the term $(w_1 - \mu)$. The essential point is that the impact of these redundancy costs is to face firms with additional potential sunk costs, $\mu(L - l_1)$ for $L > l_1$, and not higher variable costs.

In fact, the equilibrium point N of figure 1 could be found again for a reaction function which combines simultaneously $(d\beta > 0)$, which tends to make the reaction function steeper, and $(d\mu > 0)$, which tends to make the reaction function flatter. Hence, a policy-mix strategy (emission trading plus increased labor market rigidity) could reduce or eliminate the negative impact on production brought about by an emission trading scheme. This is possible since μ is set by the government, and not by the market like β. More precisely, we can write the following corollary:

Corollary 1 *If μ is set such that $\mu = (k_1^{11}/h_1^{11})\beta$, neither the environmental constraint (emission trading) nor the social constraint have any impact on production decisions of the domestic firm.*

Proof. Substitute in (9). ■

This implies, of course, that the emission trading system has no impact on emissions via production decisions, but in a problem like climate change long-term emission reductions are more relevant and they will be associated to technology decisions, which we will analyze in the next section. Government's interest to keep production constant can be explained in two ways: (i) the preoccupation about unemployment (very strong in Europe), since lower production implies in our model lower employment in the domestic country, and (ii) the interest in not reducing Gross Domestic Product (GDP), since growth is generally the basic tool to evaluate overall governmental policies (as long as price effects do not offset the negative impact of reduced production).

On the other hand, it is also immediate to show that increasing the environmental constraint ($d\beta > 0$) and at the same time reducing the rigidity of the markets ($d\mu < 0$), a policy often recommended for continental Europe, implies to create two incentives to reduce production, thus enabling an increased market share for foreign firms.

4 Firms' optimal technology decisions

Assuming that a duopoly equilibrium prevails, the implicit Cournot-Nash equilibrium solutions for the *ex post* determination of the duopolists' output level are represented by $y_1^* = q_1^*(x_1, x_2)$ and $y_2^* = q_2^*(x_1, x_2)$. For commodity we drop the asterisk in what follows, however, the output values used in this section are equilibrium values. Substituting these expressions into the general form of the profit functions we get:

$$\begin{aligned} g_1 &= R_1(q_1(x_1, x_2), q_2(x_1, x_2)) - (w_1 - \mu)h_1(q_1(x_1, x_2), x_1) \\ &\quad -(p_1 + \beta)k_1(q_1(x_1, x_2), x_1) - v_1 x_1 - \mu L + \beta E \qquad (10) \\ g_2 &= R_2(q_1(x_1, x_2), q_2(x_1, x_2)) - w_2 h_2(q_2(x_1, x_2), x_2) \\ &\quad -p_2 k_2(q_2(x_1, x_2), x_2) - v_2 x_2 \qquad (11) \end{aligned}$$

Maximizing these profit functions with regard to technology investment levels (x_1 and x_2) we obtain the following expressions for the *ex ante* first-order conditions (using (6) and (7)):

$$\begin{aligned} g_1^1 &= R_1^2 q_2^1 - (w_1 - \mu)h_1^2 - (p_1 + \beta)k_1^2 - v_1 \qquad (12) \\ g_2^2 &= R_2^1 q_1^2 - w_2 h_2^2 - p_2 k_2^2 - v_2 \qquad (13) \\ g_1^2 &= R_1^2 q_2^2 < 0, \; g_2^1 = R_2^1 q_1^1 < 0 \end{aligned}$$

The associated second-order conditions are :

$$\begin{aligned} g_1^{11} &= R_1^2 q_2^{11} + (R_1^{21} q_1^1 + R_1^{22} q_2^1) q_2^1 - (w_1 - \mu)(h_1^{21} q_1^1 + h_1^{22}) - (p_1 + \beta)(k_1^{21} q_1^1 + k_1^{22}) < 0 \\ g_2^{22} &= R_2^1 q_1^{22} + (R_2^{11} q_1^2 + R_2^{12} q_2^2) q_1^2 - w_2(h_2^{21} q_2^2 + h_2^{22}) - p_2(k_2^{21} q_2^2 + k_2^{22}) < 0 \end{aligned}$$

We note:

$$B = g_1^{11} g_2^{22} - g_1^{12} g_2^{21} > 0$$

with:

$$\begin{aligned} g_1^{12} &= R_1^2 q_2^{12} + (R_1^{21} q_1^2 + R_1^{22} q_2^2) q_2^1 - (w_1 - \mu) h_1^{21} q_1^2 - (p_1 + \beta) k_1^{21} q_1^2 \\ g_2^{21} &= R_2^1 q_1^{21} + (R_2^{12} q_2^1 + R_2^{11} q_1^1) q_1^2 - w_2 h_2^{21} q_2^1 - p_2 k_2^{21} q_2^1 \end{aligned}$$

Taking the differential of the first-order conditions, we have :

$$\begin{aligned} dg_1^1 &= g_1^{11}dx_1 + g_1^{12}dx_2 = 0 \\ dg_2^2 &= g_2^{21}dx_1 + g_2^{22}dx_2 = 0 \end{aligned}$$

The slope of the reaction functions for firms 1 and 2 are:

$$\begin{aligned} \frac{dx_2}{dx_1} &= -\frac{g_1^{11}}{g_1^{12}} < 0 \ \text{ if } g_1^{12} < 0 \\ \frac{dx_2}{dx_1} &= -\frac{g_2^{21}}{g_2^{22}} < 0 \ \text{ if } \ g_2^{21} < 0 \end{aligned}$$

Noting:

$$\begin{aligned} C &= R_1^2 q_2^{11} + (R_1^{22} q_2^1 + R_1^{21} q_1^1) q_2^1 - w_1(h_1^{21} q_1^1 + h_1^{22}) - p_1(k_1^{21} q_1^1 + k_1^{22}) \\ D &= k_1^{21} q_1^1 + k_1^{22} \\ E &= R_1^2 q_2^{12} + (R_1^{21} q_1^2 + R_1^{22} q_2^2) q_2^1 - w_1 h_1^{21} q_1^2 - p_1 k_1^{21} q_1^2 \\ F &= k_1^{21} q_1^2 \\ G &= h_1^{21} q_1^1 + h_1^{22} \\ H &= h_1^{21} q_1^2 \end{aligned}$$

we have:

$$\frac{dx_2}{dx_1} = -\left[\frac{C - \beta D + \mu G}{E - \beta F + \mu H}\right]$$

We can now write the following proposition:

Proposition 3 *Without social constraint ($\mu = 0$), the introduction of an emission trading system*

(i) *induces a higher relative level of technology in the domestic firm if $q_1^1 < -k_1^{22}/k_1^{21}$.*

(ii) *may induce a lower relative level of technology in the domestic firm only if $q_1^1 > -k_1^{22}/k_1^{21}$*

Proof. The introduction of an emission trading system implies an increase from $\beta = 0$ to $\beta = \beta^*$ (where β^* is the permit price in the market). Then, dx_2/dx_1 increases if and only if:

$$-\left[\frac{C}{E}\right] < -\left[\frac{C - \beta^* D}{E - \beta^* F}\right]$$

or:

$$ED - CF > 0 \tag{14}$$

We know that $F > 0$ and (starting from a position where $g_1^{12} < 0$) $E < 0$. In addition, with

$$q_1^1 < -\frac{k_1^{22}}{k_1^{21}} \text{ (sufficient condition)}$$

we have $D < 0$ and $C < 0$ (since $g_1^{11} = C - \beta^* D < 0$). Hence, we can ensure $ED - CF > 0$.

On the contrary, dx_2/dx_1 decreases if and only if (14) is inversed (i.e. $ED - CF < 0$). This condition is checked for some values of q_1 such that:

$$q_1^1 > -\frac{k_1^{22}}{k_1^{21}} \text{ (necessary condition)}$$

■

The formulation of the proposition stresses the point that we can ensure a positive impact on the level of technology in the domestic firm if: $q_1^1 < -k_1^{22}/k_1^{21}$, while we cannot preclude this positive impact if: $q_1^1 > -k_1^{22}/k_1^{21}$. This impact on technology decisions will reduce emissions in the domestic country (since $k_1^2 < 0$).

That is, if the impact of an increase in technology on the optimal output (q_1^1) is small (smaller than a positive value $-k_1^{22}/k_1^{21}$) the firm in country 1 is interested in increasing technology since this will increase energy efficiency (reducing the number of permits to buy per unit of output) with a reduced cost in terms of new permits to buy due to higher production. On the contrary, if (q_1^1) is large, the additional permits that the firm has to buy due to the increase in production associated with a higher level of technology may not be worth the increase in efficiency obtained by the enhanced technology.

We will now analyze the impact of the social constraint on the technology decisions induced by an emission trading system. We will first analyze the impact of existing labor market rigidity (μ) at the moment where the emission trading system is launched. Afterwards, we will study the impact of a simultaneous increase of the environmental and the social constraint. On the first issue, we can write the following proposition:

Proposition 4 *The presence of a social constraint when an emission trading system is established favors higher relative levels of technology in the domestic firm if:*

$$-\frac{k_1^{22}}{k_1^{21}} < -\frac{h_1^{22}}{h_1^{21}}$$

Proof. *The equivalent to condition (14) is now:*

$$-\left[\frac{C+\mu G}{E+\mu H}\right] < -\left[\frac{C-\beta^{*}D+\mu G}{E-\beta^{*}F+\mu H}\right]$$

or:

$$(ED-CF)+\mu\,(DH-GF)>0 \tag{15}$$

The new term in (15) is positive (with $\mu > 0$) as long as $k_1^{22}h_1^{21} > h_1^{22}k_1^{21}$. ■

That is, with $q_1^1 < -k_1^{22}/k_1^{21} < -h_1^{22}/h_1^{21}$ we can ensure a positive impact on technology decisions, since $(ED-CF)$ (see proposition (3)) as well as $\mu\,(DH-GF)$ are positive. If $q_1^1 > -k_1^{22}/k_1^{21}$ (assertation (ii) in proposition (3)), the chances of having a positive impact on technology decisions increase as long as $-k_1^{22}/k_1^{21} < -h_1^{22}/h_1^{21}$, since we have an additional positive term $\mu\,(DH-GF)$, compared to the situation analyzed in proposition (3(ii)).

Hence, two ratios are compared. The ratio formed dividing (i) the sensitivity of k_1^2 (the efficiency of technology to reduce energy requirements) to changes in the level of technology by (ii) the sensitivity of this efficiency to changes in output. And the equivalent ratio for the efficiency of technology to reduce labor requirements. That is, we are asking what grows faster with technology (compared to its reduction with production): technology efficiency to reduce energy consumption or technology efficiency to reduce labor. If technology efficiency to reduce energy consumption grows relatively faster, the existence of a social constraint will enhance technology decisions in the domestic country. This result is relevant in Europe, since the assumption of a rigid market is easy to maintain for some Europeans countries (e.g. France or Germany) while it is much harder for others (e.g. the United Kingdom).

In the section on production decisions we proposed to set $\mu = \beta k_1^{11}/h_1^{11} = \mu^*$ to eliminate the undesired consequence of emission trading of reducing domestic production. The question arises whether this practice permits to keep the benefits on technology decisions of the emission trading system. In proposition (4) we have studied the impact of an existing social constraint on the technology decisions associated to an emission trading system. Now we analyze the option of introducing simultaneously an emission trading system and a social constraint (as discussed in the section on production decisions). We can write the following proposition (remark that conditions (i) and (ii) are the same as in proposition (3)):

Proposition 5 *If the level of production has no impact on the efficiency of technology to reduce labor requirements ($h_1^{21} = 0$), simultaneous introduction of an emission trading system and a social constraint such that $\mu = (k_1^{11}/h_1^{11})\beta$:*

(i) *induces a higher relative level of technology in the domestic firm if* $q_1^1 < -k_1^{22}/k_1^{21}$.

(ii) *may induce a lower relative level of technology in the domestic firm only if* $q_1^1 > -k_1^{22}/k_1^{21}$

Proof. The equivalent to condition (14) is now:

$$-\left[\frac{C}{E}\right] < -\left[\frac{C - \beta^*\left(D + \frac{k_1^{11}}{h_1^{11}}G\right)}{E - \beta^*\left(F + \frac{k_1^{11}}{h_1^{11}}H\right)}\right]$$

or

$$(ED - CF) + \frac{k_1^{11}}{h_1^{11}}(CH - EG) > 0 \tag{16}$$

With $h_1^{21} = 0$ the new term in (16), compared to equation (14), is positive ($H = 0$ and $G > 0$). For the first term, the discussion in proposition (3) applies. ■

Hence, as long as $h_1^{21} = 0$ the simultaneous introduction of the emission trading and the social constraint (with $\mu = \mu^*$) has a positive impact on relative levels of technology if $q_1^1 < -k_1^{22}/k_1^{21}$, as in proposition (3). In addition, when $q_1^1 > -k_1^{22}/k_1^{21}$ the chances to have a positive impact are higher than in the case where $\mu = 0$, since (16) has an additional positive term compared to (14).

The assumption that $h_1^{21} = 0$ is reasonable. In fact, a number of technologies[8] used to increase energy efficiency (and to reduce emissions) do not have any impact on the amount of labor used (i.e. $h_1^2 = 0$ for any level of production). Of course, this does not mean that $h_1^{21} = 0$ only holds for these kind of technologies, since a constant impact of technology on labor requirements is enough.

However, if $h_1^{21} < 0$, we can also have positive impacts on technology decisions with $\mu = \mu^*$. In fact, working on (16) it is possible to show that $-h_1^{22}/h_1^{21} < q_1^1$ and $h_1^{11}k_1^{21} > k_1^{11}h_1^{21}$ are sufficient conditions[9] for the results (i) and (ii) in proposition (5) to hold. That is, to ensure positive impact on technology decisions we need the sensitivity of the optimal output to variations in technology (q_1^1) to be lower than a certain value (see proposition 3), but we also need this sensitivity to be higher than a certain level given by

[8] For example, if we change a conventional diesel motor for a turbo-diesel in a car (or a truck) we reduce energy consumption but we still need the same driver.

[9] The condition ($h_1^{11}k_1^{21} > k_1^{11}h_1^{21}$) is very strong, since $ED - (k_1^{11}/h_1^{11})EG$ are positive values that have not been taken into account. Hence, the positive impact on technology decisions has strong chances to occur even if this condition does not hold.

the sensitivity of labor efficiency. The larger the difference between $-h_1^{22}/h_1^{21}$ and $-k_1^{22}/k_1^{21}$, the larger the options that q_1^1 lies in-between. Hence, we can say that this positive impact on technology decisions is more likely to happen if the impact of the technology level on the efficiency of technology to reduce energy efficiency is large, while the opposite is true for the labor demand. In addition, we need the ratios formed with the second derivatives for labor and technology (h_1^{11}/k_1^{11} and h_1^{22}/k_1^{22}) to be larger than the ratio formed with the cross-derivatives (h_1^{21}/k_1^{21}).

Now, if we take the results on the production and the technology decisions together we can show that establishing an emission trading system and setting the social constraint such that $\mu = \mu^*$ has (i) no impact on production decisions (corollary 1) and (ii) will have a positive impact on relative technology levels if certain conditions are met. First, we need the condition for this positive impact without the social constraint to be met (see[10] proposition (3)). However, this condition should in any case be met when an emission trading system is established, since otherwise only impacts on production would arise (which we assume to be seen as negative). Hence, for the discussion on the convenience of setting the social constraint equal to μ^* we can assume that this condition is fulfilled (i.e. if it is not, no emission trading system should be set up in that sector). Proposition (5) says, under this assumption, that the positive impact on relative technology levels is guaranteed as long as the level of production has no impact on the efficiency of technology to reduce labor requirements ($h_1^{21} = 0$). As stated above, this condition is met for a large number of technologies (if this condition is not fulfilled, the conditions to obtain this positive impact on technology are more complicated, and thus more difficult to check if they hold in the sectors under consideration).

To sum up, following the strategy of setting the social constraint equal to μ^*, will always avoid impacts on production of the emission trading system and will allow, for a number of technologies, the positive impact on technologies we are looking for (in fact, it may even enhance this impact). As already stated, this impact on technology decisions will reduce emissions in the domestic country, so that the environmental benefits of the emission trading system are kept.

[10]Recall, however, that when $q_1^1 > -k_1^{22}/k_1^{21}$ the chances to have a positive impact are higher than in the case where $\mu = 0$.

5 Conclusion

We have shown that an emission trading system reduces the level of production of the domestic firm, while the existence of a social constraint leads to an increase in production. If the government is interested in keeping the levels of production despite the emission trading system, an increase of the social constraint may be an option. As stated, this is only possible as long as the survival of the firms is not endangered.

However, this alternative reduces the impact of the emission trading system on the environment via production reductions. Nevertheless, for a problem like climate change long term emissions may well be more relevant and these are related to technology decisions. Our analysis has shown the conditions under which the emission trading system will have a positive impact on technology decisions in the domestic country. Furthermore, we have shown the conditions under which this positive impact can be enhanced by the social constraint.

Combining the results on production and on technology, we have shown that a situation where production reductions are eliminated while technology decisions are enhanced is possible, reducing thus emissions with no costs associated with reduced production.

Difficulties associated with practical implementation of these results are recognized. Nevertheless, our analysis highlights important interactions between emission trading, labor market rigidity and international competition, which have to be taken into account while designing an emission trading system, or while introducing measures to reduce market rigidity, two of the key politics to be implemented in the European Union in the near future. That is, increasing market rigidity may be an odd option to reduce international competition distortions brought about by an emission trading system. However, the results of our simple model suggest the need to analyze carefully the interrelations of these two policies in more complex models before setting up, at the same time, an emission trading system and a more flexible labor market.

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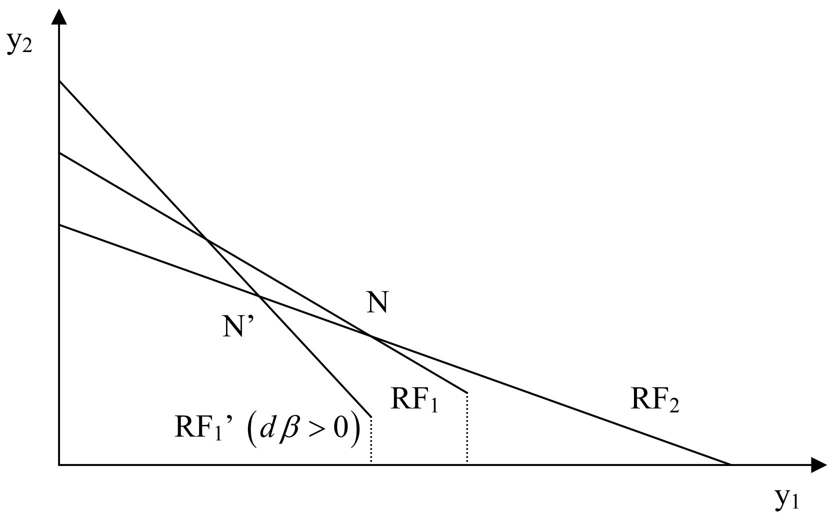

Figure 1